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Abstract

In late 1999 and early 2000, USDA surveyed 28 ethanol plants, both wet and dry mills, to estimate their 1998 costs of production (net corn costs and cash variable costs). These ethanol plants processed more than 400 million bushels of corn and sorghum in 1998 to produce more than 1.1 billion gallons of ethanol. The average variable cost of production of ethanol (the sum of the net corn cost plus net variable operating costs) weighted by industry sector was 93.9 cents per gallon. The net feedstock cost averaged about 53 cents per gallon for dry mills and 48 cents per gallon for wet mills.

Keywords: ethanol costs of production, net corn costs, operating costs, dry mills, wet mills.

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Summary

Ethanol's role in the U.S. fuel market has grown steadily. The ethanol industry increased from about 20 million gallons in 1979 to over 1,700 million gallons by the end of 2001. Current production of ethanol accounts for about 1.3 percent of total gasoline fuel used in U.S. transportation. Currently there are 58 ethanol plants in 19 States and with more than 1.9 billion gallons of annual production capacity.

The total cost of producing ethanol is composed of three elements: capital-related charges, net feedstock costs, and variable operating costs. In this analysis, detailed information is provided for net feedstock costs and variable operating costs.

USDA contracted with Bryan and Bryan Inc. International to conduct a survey of ethanol production costs during 1999 and early 2000. Ethanol plants with more than 1 million gallons of ethanol production per year were included in the survey. Twenty-eight ethanol plant owners, representing more than 1.1 billion gallons of ethanol production (1998), responded. Both dry- and wet-milling processes were included among the surveyed plants. Generally, the cost data reported here refer to calendar year 1998.

Feedstock costs include expenses for the purchase of corn, sorghum, and other feedstock. The average feedstock cost for all surveyed plants was \$0.87 per gallon of ethanol produced. The net feedstock cost ranged from \$0.44 to \$0.88 per gallon of ethanol produced.

Cash operating expenses include electricity, fuels, waste management, water, enzymes, yeast, chemicals, repair and maintenance, labor, management, administration, taxes, and insurance. The average variable cost for all surveyed plants was \$0.45 per gallon of ethanol produced. The average variable cost for wet mills was \$0.04 per gallon more than for dry mills. Variable costs of production of ethanol, weighted by industry sector, totaled \$0.94 per gallon in 1998.

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Hosein Shapouri, Paul Gallagher,
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Introduction

Ethanol's role in the U.S. fuel market has grown steadily. More than 1.6 billion gallons of ethanol was produced in 2000 (from more than 500 million bushels of corn), and projected production for 2001 is over 1.7 billion gallons. About a fourth of ethanol is used in reformulated gasoline, half is used in conventional gasoline as an octane booster, and the remainder is used in the U.S. Winter Oxygenated Fuel Program and in Minnesota's Oxygenated Fuel Program.

Continued expansion of ethanol use depends on many factors. Lower cost ethanol due to new processing technology should boost demand, as will ethanol's use as a replacement for MTBE in reformulated gasoline. The State of California will phase out MTBE by December 31, 2002, and the Federal Government is considering the possibility of a Federal MTBE ban that could become effective within 4 years. But removal of the minimum oxygen requirement for reformulated gasoline could reduce ethanol demand.

Regardless of the outcome of the MTBE issue, other regulatory developments point toward expanding ethanol demand. In the next 5 years, Federal regulations will require sulfur reductions in gasoline. As a result, demand for octane-enhancing additives like ethanol could increase. Also, high oil prices and continued U.S. reliance on foreign oil might encourage production of domestic fuel. Specifically, Congress could mandate renewable fuels in gasoline. Another potential source of future growth is the blending of ethanol into diesel fuel.

This report presents production cost estimates for ethanol and assesses the competitiveness of the U.S.

ethanol industry. A brief discussion of the industry and policies is presented first. Then the results of the 1998 survey of ethanol plants are presented in detail. The effects of technology on reducing ethanol costs of production during the last 10 years are discussed. Finally, the results of the current ethanol cost-of-production survey are compared with the 1987 survey results for selected ethanol plants.

Ethanol Industry and Policy

Ethanol production increased from about 20 million gallons in 1979 to over 1,600 million gallons by the end of 2000. Current production of ethanol amounts to about 1.3 percent of total gasoline fuel used in U.S. transportation. As of December 2001, there were 58 ethanol plants located in 19 States with a combined annual production capacity of more than 1.9 billion gallons.

The fuel ethanol industry started 20 years ago with an exemption from the Federal excise tax on gasoline, various State tax incentives, capital subsidies, and loans. The Federal excise tax exemption is 5.3 cents per gallon of gasoline blended with 10 percent ethanol or 53 cents per gallon of ethanol blended. The tax exemption approximately equalizes the price of ethanol and conventional gasoline, and thus encourages its use as a gasoline extender. The Federal tax exemption dropped to \$0.53 on January 1, 2001, and is scheduled to decline to \$0.52 on January 1, 2003, and to \$0.51 on January 1, 2005. Under current law, the Federal tax exemption will expire on December 31, 2007.

At least 13 States have some kind of ethanol incentive (table 1). These incentives range from a 1-cent-per-gallon excise exemption in Connecticut to a 40-cent-per-gallon producer payment in Wyoming.

State ethanol incentives can be divided into excise exemptions, sales tax exemptions, and producer payments. The producer payment is equal to 20 cents per gallon in Minnesota, Missouri, Nebraska, and South Dakota, 30 cents per gallon in Montana, and 40 cents per gallon in Wyoming.

Ethanol Production Process

Ethanol production facilities include both wet- and dry-milling operations. Wet-mill facilities are “bio-refineries” producing a host of high-valued products such as high-fructose corn syrup (HFCS), dextrose, glucose syrup, vitamins, food and feed additives, and corn refinery byproducts such as corn gluten feed, corn gluten meal, corn oil, and carbon dioxide. In the wet process, milling and processing are more elaborate because the grain must be separated into its components including starch, fiber, gluten, and germ. The germ is removed from the kernel, and corn oil is extracted from the germ. The remaining germ meal is added to fiber and the hull to form corn gluten feed (CGF). Gluten is also separated to become corn gluten meal (CGM), a high-protein animal feed. In the wet-milling process, a starch solution is separated from the solids, and fermentable sugars are produced from the starch. These sugars are fermented to ethanol, which is recovered by distillation and dehydration at a concentration of approximately 99 percent.

In the dry-mill process, the clean corn is ground and mixed with water to form a mash. The mash is cooked, and enzymes are added to convert starch to sugar, then yeast is added to ferment the sugars, producing a mixture containing ethanol and solids. The beer (alcohol-water mixture) is then distilled and dehydrated to create fuel-grade 99-percent ethanol. The solids remaining after distillation are dried to produce distillers’ dried grains (DDG) with 27-percent protein and are sold as an animal feed supplement.

Ethanol Production Technology

Ethanol production technologies have changed significantly during the past 20 years. Ethanol plants have employed well-known technologies from related industries in order to reduce ethanol production costs. Ethanol producers have adopted new technologies such as process computer control, high-toler-

Table 1--Ethanol incentives by State

Ethanol incentive		
Alaska	4¢/gal	winter blends only
Connecticut	1¢/gal	excise exemption
Hawaii	4%	sales tax exemption
Idaho	2.1¢/gal	excise exemption
Illinois	2%	sales tax exemption
Iowa	1¢/gal	excise exemption
Minnesota	20¢/ga	producer payment
Missouri	20¢/gal	producer payment
Montana	30¢/gal	producer payment
Nebraska	20¢/gal	producer payment
Ohio	1¢/gal	(restrictions apply)
South Dakota	20¢/gal	producer payment
Wyoming	40¢/gal	producer payment

Source: *Oxy-fuel News*, Nov. 26, 2001.

ance yeasts, continuous fermentation, co-generation of steam and electricity, and molecular sieve driers. Early ethanol plants used azeotropic distillation to dehydrate ethanol. Today, almost all ethanol plants use molecular sieves for dehydration. This technology alone reduces energy use by more than 3,000 Btu’s per gallon of ethanol produced.

Essentially all new ethanol plant capacity is in the form of dry mills. Standardized design of dry-mill facilities has reduced the capital cost substantially, with some new plants reported to cost about \$1.07 per annual gallon versus \$1.75 to \$2.00 for earlier facilities’ first costs. New dry-mill ethanol plants are more energy efficient, requiring about 36,000 Btu’s of thermal energy and 1.1 kilowatts of electricity to produce 1 gallon of ethanol. New techniques have been developed for upgrading waste products to marketable commodities, increasing the value of traditional byproducts, and recovering waste heat for plant use.

The cost of production of ethanol for the dry-milling process could decline further as new byproducts such as corn oil and corn fiber are produced. These could lower processing costs by 5 to 10 cents per gallon. There may also be capital cost reductions associated with new plants that are capable of recovering oil and fiber, further reducing the total cost of production. There is also the potential to produce new byproducts such as vitamins, corn fiber oil, corn fiber gum, and zein by both the dry- and wet-milling processes.

Total Costs of Production

The total cost of producing ethanol is composed of three elements: capital-related charges, net feedstock costs, and variable operating costs. In this analysis, detailed information is provided for net feedstock costs and variable operating costs. The capital component depends on the facility's outstanding debt and loan structure. One use of these data is to project future production costs for the highest cost ethanol producers, most likely new producers whose cost structure must include full debt coverage. The survey cost data can be combined with reported capital costs for new plants and debt and equity scenarios to estimate future ethanol costs.

USDA 1998 Survey

Bryan and Bryan Inc. International (BBI International) conducted ethanol production cost interviews during 1999 and early 2000. Ethanol plants with more than 1 million gallons of ethanol production per year were included in the survey. Twenty-eight ethanol plant owners, representing more than 1.1 billion gallons of ethanol production (1998), responded. Survey data include both dry- and wet-milling processes. Generally, the cost data refer to calendar year 1998.

Ethanol producers provided detailed data on cash operating expenses, feedstock costs, and credit for

Table 2—Denatured ethanol cash operating expenses and net feedstock costs, dry- and wet-milling processes

Item	Unit	Grain		Nongrain	U.S. total
		Wet-milling process	Dry-milling process	Dry-milling process	
Feedstock:					
Corn	1,000 bu	280,300	134,216	243	414,759
Sorghum	1,000 bu	0	7,549	243	7,793
Total	1,000 bu	280,300	141,765	486	422,552
Alcohol production:					
Fuel	1,000 gal	657,215	370,813	10,174	1,038,202
Industrial	1,000 gal	89,600	47	3,400	93,047
Beverage	1,000 gal	4,950	2,805	0	7,755
Total	1,000 gal	751,765	373,665	13,574	1,139,004
Weighted data by ethanol output					
Ethanol yield	Gal/bu	2.682	2.636	NA	2.666
Feedstock costs	Dol./gal	0.9065	0.8151	0.2000	0.8681
Byproduct credits	Dol./gal	0.4270	0.2806	0.0090	0.3740
Net feedstock costs	Dol./gal	0.4795	0.5345	0.1910	0.4941
Cash operating expenses:					
Electricity	Dol./gal	0.0332	0.0409	0.0388	0.0358
Fuels	Dol./gal	0.0785	0.0901	0.0460	0.0819
Waste management	Dol./gal	0.0263	0.0056	0.0010	0.0192
Water	Dol./gal	0.0130	0.0025	0.0000	0.0094
Enzymes	Dol./gal	0.0581	0.0559	0.0325	0.0571
Yeast	Dol./gal	0.0269	0.0068	0.0146	0.0202
Chemicals	Dol./gal	0.0296	0.0270	0.0313	0.0288
Denaturant	Dol./gal	0.0322	0.0230	0.0315	0.0292
Maintenance	Dol./gal	0.0478	0.0359	0.0576	0.0440
Labor (O&M, supervision & benefits)	Dol./gal	0.0763	0.0732	0.1130	0.0757
Administrative costs	Dol./gal	0.0378	0.0366	0.0518	0.0376
Other costs	Dol./gal	0.0000	0.0196	0.0083	0.0066
Total	Dol./gal	0.4597	0.4171	0.4264	0.4453
Total cash and net feedstock costs	Dol./gal	0.9392	0.9516	0.6174	0.9394

byproducts. To maintain confidentiality, data were aggregated by the production capacity of ethanol to yield average costs for the industry by type of process and by size of operation for dry mills.

The survey was very complete. Ethanol plants that participated in the ethanol cost-of-production survey represent much of the industry production capacity. The plants that participated in the survey represented 751.8 million gallons of wet-mill grain-based ethanol production and 373.7 million gallons of dry-mill grain-based ethanol production. Production for plants utilizing waste sugar and starch was 13.6 million gallons.

Respondents provided data on cash operating costs. Production costs include feedstock costs, byproduct credits, and cash operating costs. Feedstock and byproduct costs are combined into the net feedstock cost—the cost of feedstock to produce a gallon of denatured alcohol minus the value of byproducts. Production costs are tabulated for dry-milling and wet-milling processes. Further, costs for dry milling are divided in two groups; those using grain feedstock and those using waste sugar and starch.

The survey data are provided in tables 2 and 3.

Table 3—Ethanol cash expenses and net feedstock costs, dry-milling process by plant size, 1998

Item	Unit	Small	Medium	Large
Feedstock:				
Corn	1,000 bu	9,670	70,047	54,500
Sorghum	1,000 bu	3,431	4,118	0
Total	1,000 bu	13,101	74,164	54,500
Alcohol production:				
Fuel	1,000 gal	33,910	190,403	146,500
Industrial	1,000 gal	0	47	0
Beverage	1,000 gal	0	2,805	0
Total	1,000 gal	33,910	193,255	146,500
Ethanol yield	Gal/bu	2.588	2.606	2.688
Feedstock costs	Dol./gal	0.9350	0.7898	0.8207
Byproduct credits	Dol./gal	0.3398	0.2613	0.2923
Net feedstock costs	Dol./gal	0.5952	0.5285	0.5284
Cash operating expenses:				
Electricity	Dol./gal	0.0502	0.0374	0.0434
Fuels	Dol./gal	0.1284	0.1029	0.0644
Waste management	Dol./gal	0.0005	0.0057	0.0065
Water	Dol./gal	0.0036	0.0043	0.0000
Enzymes	Dol./gal	0.0556	0.0605	0.0497
Yeast	Dol./gal	0.0092	0.0105	0.0014
Chemicals	Dol./gal	0.0310	0.0276	0.0252
Denaturant	Dol./gal	0.0305	0.0242	0.0197
Maintenance	Dol./gal	0.0348	0.0291	0.0453
Labor (O&M, supervision, & benefits)	Dol./gal	0.0962	0.0707	0.0712
Administrative costs	Dol./gal	0.0475	0.0394	0.0305
Other costs	Dol./gal	0.0054	0.0336	0.0043
Total	Dol./gal	0.4929	0.4459	0.3616
Total cash and net feedstock costs	Dol./gal	1.0881	0.9744	0.8900

Feedstock Costs

Feedstock costs include expenses for the purchase of corn, sorghum, and other feedstocks. The average feedstock costs for all survey plants was \$0.87 per gallon of ethanol produced. The feedstock costs (corn) for the wet-milling process were 9 cents per gallon higher than for dry-mill plants. High costs of feedstock could be attributed to the larger volume of corn required for wet-mill plants and the associated increased transportation cost. The average feedstock cost for dry-mill plants using waste sugar and starch was \$0.19 per gallon. Some waste sugar plants probably receive a tipping fee for handling the sugar and waste products.

According to the survey, dry mills purchased both corn and sorghum feedstock, but large plants purchased corn only. The average feedstock cost was \$0.94 per gallon for small plants, \$0.79 for medium-size plants, and \$0.82 for large plants.

Byproduct Credits

Wet-mill ethanol plants produce many byproducts including ethanol, carbon dioxide, corn gluten feed, corn gluten meal, and corn oil. In contrast, dry-mill ethanol plants produce ethanol, carbon dioxide, and distillers' dried grains. Nine ethanol plants indicated that they sold wet distillers' grains in 1998. The average byproduct credit for wet mills was \$0.43 per gallon versus \$0.28 per gallon for dry mills. Only six ethanol plants captured and sold carbon dioxide in 1998.

Net Feedstock Costs

Net feedstock cost is an important variable cost factor, ranging from 44 cents to 88 cents per gallon of ethanol for the individual ethanol plants that participated in the survey.

Historical data for net corn cost are provided in table 4. These were estimated based upon USDA data and were derived from slightly different ethanol plant conversion factors than those found in this survey. Recently, corn prices have varied from \$1.92 per bushel in 1999 to \$3.82 per bushel in 1996. The price of corn byproducts is related to the price of soybean meal and oil. During the past 10 years, the net corn cost for wet mills ranged from \$0.36 per

gallon in 1999 to \$0.91 per gallon in 1996. During the same period, the net corn cost for dry mills ranged from \$0.44 per gallon in 1999 to \$0.95 per gallon in 1996. Corn and byproduct prices declined significantly in 1999 and 2000.

Cash (Variable) Operating Costs

Variable operating expenses include electricity, fuels, waste management, water, enzymes, yeast, chemicals, repair and maintenance, labor, management, administration, taxes and insurance, and miscellaneous expenses. Fuel includes expenses for natural gas, coal, and purchased steam.

Electricity and fuel are the largest components of operating expenses. Average energy expenditure for all U.S. ethanol plants was 11.8 cents per gallon of ethanol produced in 1998. Energy expenses are lower in wet mills (11.2 cents per gallon) than in dry mills (13.1 cents per gallon) because the large wet mills employ cogeneration of steam and electricity. On the other hand, maintenance is higher in wet mills, averaging 4.78 cents per gallon versus 3.59 cents in dry mills.

Waste management, water, yeast, and denaturant costs were significantly higher in wet mills than in dry, and their costs for enzymes, chemicals, maintenance, labor, and administration were somewhat higher.

Some components of operating expenses varied widely across the plants in the survey. For instance, maintenance ranged from 1 to 10 cents per gallon of ethanol produced, and labor ranged from 4 to 11 cents per gallon. The wide ranges probably reflect accounting differences and the use of contract maintenance. Electricity costs ranged from 2 to 7 cents per gallon of ethanol.

Other components showed less variation across firms. Enzymes and chemicals were nearly constant at 6 cents and 3 cents per gallon, respectively. Gasoline for denaturing ranged from 2 to 4 cents per gallon. Waste management varied from less than 1 cent to slightly over 2 cents per gallon. Water varied from less than 1 cent to over 3 cents. Generally, larger plants incur higher expenses for water because they have waste treatment units.

Table 4—Net corn costs per gallon of ethanol for wet- and dry-milling processes

Year	No. 2 Yellow	Corn and corn byproduct prices				Wet mill			Dry mill		
		Oil	Gluten feed	Gluten meal	Distillers' dried grain	Corn cost	Byproduct credits	Net corn cost	Corn cost	Byproduct credits	Net corn cost
		<i>Dollars per bushel</i>	<i>Cents per pound</i>	<i>Dollars --- per ton ---</i>		<i>----- Dollars per gallon -----</i>					
1990	2.45	26.51	100.15	245.58	122.14	0.98	0.54	0.44	0.94	0.40	0.54
1991	2.40	28.36	101.57	256.70	124.49	0.96	0.56	0.40	0.92	0.41	0.52
1992	2.32	23.89	102.80	259.72	124.58	0.93	0.54	0.39	0.89	0.41	0.49
1993	2.27	21.52	87.99	296.53	121.84	0.91	0.51	0.04	0.87	0.40	0.47
1994	2.40	27.22	89.59	262.50	111.71	0.96	0.53	0.43	0.92	0.37	0.56
1995	2.70	26.67	81.34	244.02	110.05	1.08	0.51	0.57	1.04	0.36	0.68
1996	3.82	24.52	116.25	332.40	168.66	1.53	0.62	0.91	1.47	0.52	0.95
1997	2.67	24.87	83.99	345.22	134.19	1.07	0.54	0.63	1.03	0.44	0.59
1998	2.23	29.90	64.86	260.44	91.16	0.89	0.48	0.41	0.86	0.30	0.56
1999	1.92	23.59	58.77	231.88	89.33	0.77	0.41	0.36	0.74	0.29	0.44

The management, administration, insurance, and tax expenses ranged from 4 to 7 cents per gallon. Some of these differences may be attributed to differences in accounting for management and personnel, with the small and mid-sized plants allocating less of payroll to management overhead. Wet-mill ethanol plants have slightly higher administrative costs than dry-mill ethanol plants. Within the ethanol plants, administrative cost declines as size of ethanol plant increases.

Investment Cost per Gallon of Annual Capacity

Reported levels of investment per gallon of installed ethanol capacity for existing plants ranged from \$1.07 to \$2.39. The variation in capital investment per gallon can be attributed to the conversion process, refinement of the design, use of used equipment, and age of the ethanol plant. Typically, a wet mill requires a larger capital investment than a dry mill of the same size.

Investment costs depend on whether production was added to an existing mill, a closed plant was retrofit-

ted and reopened, or a new ethanol plant was constructed. Many older ethanol plants were over-designed, allowing additional production capacity to be added with minimal additional investment. Survey results showed that 17 ethanol plants expanded their production capacities from 294 million gallons per year at startup to 475 million gallons per year in 1998. The cost of expansion ranged from \$0.33 to \$0.88 per gallon.

Ethanol Sales and Shipments

Fifty-one percent of ethanol produced in 1998 was sold to terminal storage and 43 percent to blenders; 60 percent of ethanol sales were cash, while 32 percent were credit. Ninety-seven percent of ethanol produced in 1998 was sold in the domestic market, and 3 percent was exported.

In 1998, 38 percent of ethanol was hauled by truck, 48 percent was shipped by rail, and 14 percent was hauled by barge. Of ethanol byproducts, 42 percent were shipped by truck in 1998, 40 percent by rail, and 9 percent by barge.

Table 5—Comparison of ethanol cash operating costs, 1987 and 1998

	1998 ¹ Wet mills	1987 ² Large plants	1998 All dry mills	1987 Dry mills— small & mid- size plants
<i>Cents per gallon</i>				
Energy	11.17	16.90	13.10	18.50
Ingredients ³	11.43	10.20	8.97	8.30
Operating labor and maintenance	12.41	13.70	10.91	18.60
Management, administra- tion, insurance, and taxes	3.78	6.40	3.66	5.1
Other ⁴	7.15	NA	5.07	NA
Total	45.97	47.20	41.71	50.50

¹ 1999-2000 USDA Benchmark Survey.

² *Economics of Ethanol Production in the United States*, AER-607, U.S. Dept. Agr., Econ. Res. Serv., 1989.

³ Includes enzymes, yeasts, and chemicals.

⁴ Includes expenses for waste management, water, denaturant, corporate overhead, and other non-listed costs.

Comparison of Ethanol Production Costs, 1998 and 1987

The last ethanol production cost survey described the industry in 1987. Table 5 provides a comparison with the 1998 USDA survey data. Since the size distribution of dry mills is different in the two surveys, a comparison of operating cost data may be misleading.

Wet-mill variable costs appear to have remained very stable at about 46 cents per gallon. Improved energy cost management was offset by several factors, including waste management and overhead.

In contrast, dry mills may have experienced a 15-percent reduction in operating costs, due to the effects of reduced energy, labor, and maintenance expenditures and possibly economy of scale.

Wet-mill byproduct credits were about 55 percent of corn costs in both periods. For dry mills, byproduct credits fell from 52 percent of corn expenditures to 34 percent.

Conclusions

The total cost of production is the sum of capital-related charges and the total variable costs of production. The total variable cost is the sum of the net corn cost and the variable operating costs. The total variable cost of production of ethanol weighted by industry sector was 93.9 cents per gallon in 1998.

According to the 1998 survey, the net feedstock cost averaged about 53 cents per gallon for dry mills and 48 cents per gallon for wet mills. The net corn cost is influenced by the price of corn, the price of by-products, and the conversion efficiency. While conversion efficiency has improved in recent years, its impact is small compared with price effects. Table 4 shows that the net corn cost is quite variable, and the recent historical average is about 13 to 14 cents higher than in 1998.

Variable operating costs for wet mills appear to have remained nearly constant. Dry-mill operating costs appear to have fallen substantially and are now significantly lower than those of wet mills. Future dry-mill operating costs may fall by 5 to 10 cents per gallon as recovery of corn oil and corn fiber becomes practiced commercially on a large scale.

Because the variable costs of production are very similar for larger dry mills and wet mills, new expansion is likely to be in the form of dry mills because of the lower capital investment and, therefore, lower capital-related charges.

